ADA 027450

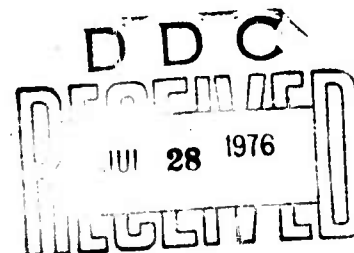# IRRADIATED ELECTRONICS RELIABILITY STUDY

July 1976

Final Report

Approved for public release; distribution unlimited.

DDC

JUL 28 1976

A

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117

This final report was prepared for the Air Force Weapons Laboratory, Kirtland AFB, NM, under Job Order 88091121. Mr. Bernd Deve (ELP) was the Laboratory Project Officer in charge.

When US Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

BERND DEVE
Project Officer

FOR THE COMMANDER

LARRY W. WOOD
Lt Colonel, USAF
Chief, Phenomenology and
  Technology Branch

JAMES L. GRIGGS, JR.
Colonel, USAF
Chief, Electronics Division

DO NOT RETURN THIS COPY. RETAIN OR DESTROY.

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFWL-TR-76-125	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* IRRADIATED ELECTRONICS RELIABILITY STUDY		5. TYPE OF REPORT & PERIOD COVERED Final Report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Bernd Deve Chris Ashley		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Weapons Laboratory (ELP) Kirtland AFB, NM 87117		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62601F; 88091121
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Weapons Laboratory (ELP) Kirtland AFB, NM 87117		12. REPORT DATE July 1976 13. NUMBER OF PAGES 16
14. MONITORING AGENCY NAME & ADDRESS*(if different from Controlling Office)*		15. SECURITY CLASS. *(of this report)* UNCLASSIFIED 15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Subsystem irradiation; Ionizing radiation; Subsystem reliability; Statistical analysis

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

In 1969 the U.S. Air Force withdrew approximately 790 modules of electronics circuitry, in the form of 10 operational guidance and control systems, from the field and irradiated them. A module consists of an average of about 25 small scale integrated circuits, 45 discrete semiconductor devices, and miscellaneous R, L, and C components. The average total dose used was approximately 1800 rads(Si) of 4.2 MeV mean bremsstrahlung. This dose was distributed over 8 to 10 pulses per system, with average half power width approximately 72 nanoseconds per pulse. The average (over all modules) maximum half-power-point-rate was

DD FORM 1473 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

about 8.4E9 rads(Si)/sec. The irradiated modules were then returned to field service.

A primary objective of the radiation tests was to determine the photocurrent induced latchup susceptibility of the guidance and control system to known short duration pulses of radiation. The purpose of this report, in contrast, is to indicate how that radiation testing affected the longer term reliability of the electronics circuitry via certain other mechanisms, assuming that any immediately obvious radiation damage was corrected.

Six years later, in 1975, failure and repair records were analyzed statistically to determine whether the radiation had functionally affected the electronics. There remained 650 irradiated modules available for this statistical analysis after culling. These modules had been carefully associated by individual serial number with approximately 1050 modules in field use which were not irradiated and which served as controls. The fraction which failed among the irradiated modules in the six years of field service was not found to be greater to a statistically significant degree than the fraction which failed among the control modules.

CONTENTS

SECTION I

INTRODUCTION

Avionic systems are customarily tested in radiation and other environments
to determine susceptibility of electronics to failure due to those environments.
Often, few samples are available for testing other than the field hardware
itself, and this cannot be allowed to suffer significant degradation in such
tests and then be returned to operational use. The question has long existed
whether radiation reduces reliability. An opportunity to gain insight into
this question appeared when ten flight hardware guidance and control systems
were withdrawn from service inventory, tested in a bremsstrahlung environment,
and returned to service.

Radiation can immediately degrade circuit reliability by such effects as
photocurrent induced latchup. The original purpose of these tests was to
determine the susceptibility of the tested electronics to this kind of immedi-
ate degradation of reliability. It is not the purpose of the present report
to comment on such immediate effects of radiation; this subject is reported in
numerous other sources.

In testing for such immediate effects, however, even at relatively low
doses and rates, there is some risk of permanently degrading the circuit
reliability in ways which are not obvious. Examples are thermomechanical
weakening of bonds, and damage to power supplies and other peripheral circuitry
as a result of temporary current overload. The present report is intended to
indicate whether radiation testing affects mid-1960s junction isolated SSI
(small scale integrated) circuitry via these longer term mechanisms, assuming
the immediately obvious effects of the radiation have been corrected.

Since detailed records were kept on the hours in service and failures
suffered in several levels of the substructure of the systems, an opportunity
was available to monitor any change in long term reliability resulting from the
radiation tests. Following six years of observations, comparisons were made to
determine if a larger failure fraction had occurred among the irradiated
systems than among identical nonirradiated systems.

SECTION II

IRRADIATION AND DATA COLLECTION

Ten operational guidance and control systems taken from the field were exposed to bremsstrahlung from the Pulserad 1590 machine located in the Transient Radiation Effects Facility at the Air Force Weapons Laboratory. The bremsstrahlung spectrum of the machine is assumed to be equivalent to monoenergetic photons of 4.2 MeV (Ref. 1). A more detailed description of the output spectrum of the Pulserad 1590 is available from tests which were performed several years ago by the US Army Electronics Command. A report on their results has recently been released (Ref. 2). Their calculated spectrum is included as appendix C.

Each of the ten systems was irradiated in eight to ten pulses, the average half power width of each pulse being about 72 ns. The systems were rotated between pulses, so that the average total dose was approximately 1800 rads(Si). The average (over all modules) maximum half-power-point-rate was about 8.4E9 rads(Si)/sec. The systems were then put back into operation and monitored.

The smallest traceable serialized unit within the system is the module. A module consists of an average of about 25 junction isolated small scale integrated circuits, 45 discrete semiconductor devices, and miscellaneous R, L, and C components. If a transistor fails, the serialized module that contained the faulty transistor is removed and replaced with an operating module. The module that failed is sent to a repair depot where the problem is diagnosed and corrected. The module is then ready for reinstallation in that or another system. Removal and repair of these serialized modules is recorded along with operating time preceding failure. Record is also made of periodic operational checks of all system modules. These records supply the information on the modules necessary for the analysis reported herein.

To ensure that radiation was the primary cause of failures and not manufacturing or assembly defects, a set of modules was required as a control group. Two control modules were used for each irradiated module, one with a serial number (SN) immediately above that of the irradiated module and the second with SN immediately below. To obtain both the plus one and minus one serial numbers from the irradiated module would be the ideal case, but this was not always possible (see below). Modules as close to the irradiated modules as could be found were used as controls to provide some assurance that an irradiated module and its nonirradiated controls were assembled at the same time, under the same conditions, and with electronic components from the same stock. More important, however, is that the irradiated module and its corresponding control modules were placed into service at the same time. Therefore it is likely that the irradiated and control module groups would have a nearly equal average number of operational hours, and any explanation for difference in failure rates between the two groups would not include module age.

All failures discussed in this report are primary failures. Primary failures are those in which a module develops a defect and fails of its own accord. If a module failed as the direct result of a failure in another module, it was called a secondary failure and was not included in this study.

Computer printout of failure and repair summaries provided the irradiated and control module data for analysis. The printout included module type, serial number, guidance system location, month installed and removed since irradiation in 1969, total hours used since 1969, number of primary failures per module, the hours each module operated since those failures were repaired, and diagnosis of primary failure.

The printout contained a total of 650 irradiated modules. This represents 82 percent of the total number of irradiated modules. The remaining 18 percent were discarded because records of the modules could not be found or the records were incomplete. Given 650 irradiated modules in the printout, one would expect 1300 nonirradiated controls (a prior and a post SN for each irradiated module). Actually, there were only 1044 control modules. This happened because quite often two or three modules were irradiated with consecutive serial numbers; for example, modules numbered 5, 6, and 7. The nonirradiated control for this group would be modules 4 and 8. Although six control modules would normally be expected for three irradiated modules, in this case there would be only two.

SECTION III

ANALYSIS

The data in the printout was first edited to eliminate possible gross anomalies due to record keeping. All the remaining modules were divided into three subcategories: power, logic, and analog modules. The result is summarized in Appendix A. In Appendix B are given the results of chi-squared (χ^2) and small sample statistical analysis of this data.

The hypothesis tested was that the incidence of primary failure is independent of test irradiation. This hypothesis was chosen because it was easy to compute expected values given independence between failures and irradiation. As an example, following is a calculation of the expected number of irradiated module failures in the power subset, assuming this independence. The numbers for computing this and all other expected value calculations are given in the module data sheet (Appendix A). To be assured that the χ^2 test will yield valid results, each expected value should be at least five.

E_{if} = expected number of modules that were irradiated and failed

= (fraction of modules irradiated) x (fraction of modules that failed)

x (total number N of modules)

$$= \frac{\text{total number modules failed}}{N} \times \frac{\text{total number modules irradiated}}{N} \times N$$

$$= \frac{201}{513} \times \frac{16}{513} \times 513$$

= 6.269 . (Observed value was 7. See Appendix B, Table 3.)

The four expected values in the 2 x 2 matrix (success-failure versus irradiated-nonirradiated) were then combined with the values actually observed to form the χ^2 statistic, using the following formula:

$$\chi^2 = \left(\sum \frac{D^2}{E} \right) - N$$

where D is observed data value; E is expected value; and N is total number of modules for that test. This experimental value for χ^2 is then compared with the

6

statistically significant value χ_0^2 (read from widely available tables):

$$\chi_0^2 \Big|_{\substack{d.f. = 1 \\ \alpha = .05}} = 3.84146$$

where d.f. = degrees of freedom and α = level of significance. For more information on chi-squared testing, consult an introductory statistics textbook.

Results of the χ^2 tests show that the data for the set of all modules, and also for the power subset, were not sufficiently significant to justify rejecting the statistical hypothesis. That is, the printout does not supply sufficient evidence to conclude that the test irradiation affected the probability of primary failure. To say that this data shows that test irradiation does not affect the probability of primary failure would be a stronger statement. This stronger statement entails the risk of a Type II error (accepting a false hypothesis). Nonetheless, the test statistics show $\chi^2 \ll \chi_0^2$; therefore it appears this stronger conclusion is also warranted by the data. The same conclusions follow from small sample analysis of the logic and analog subsets.

It will be noticed that the statistical tests used were simple, i.e., did not include such relatively sophisticated statistical analysis as Wilcoxon rank sum tests. The reasons for this are as follows. Although the expected failure values were small, they were adequate for χ^2 testing both the modules as a single class and the power subset. Also, small sample techniques were adequate for analysis of the logic and analog subsets. As to paired comparisons, such as time rank sum tests, it was intended that the correlation between failure rate and component age or production run was to be considered only if the data seemed to indict radiation. Age or production run could then be studied as an alternative explanation for failure so that radiation would not be blamed falsely. Since simple tests appear to exonerate radiation immediately, there was no need to use further statistical tests to be sure radiation is not being credited with causal effects when that credit belonged elsewhere.

Mean time between failure (MTBF) rates could not be estimated accurately for either the irradiated or the control groups. Due to high reliability electronic parts used in these guidance and control systems, only about 2 percent of the modules failed. If a substantial percentage of the modules had failed at least once, it could be assumed (for computing purposes) that the

remaining modules failed at the end of the period of observation, usino the total number of hours given in the printout for the time to failure. This would yield a lower bound on the MTBF. With a substantial number of failed parts, one might also be able tc extrapolate the MTBF using distributions applicable to semiconductor failure rates. But such a substantial failure rate did not occur. Even if enough module failures had occurred, a second problem hinders MTBF calculations. The data for both the irradiated and nonirradiated modules included only those hours of operation accumulated since 1969 (date of irradiation). Records would have to be accessed to recover the module pre-irradiation hours. If those hours were not included and the modules were in the field an average of 2 years before irradiation, then the calculated MTBF data would be 25 percent low, since only 6 of the 8 years of life would be included. Therefore, to determine MTBF, both the pre-irradiation hours and many more module failures are needed.

SECTION IV

CONCLUSIONS

Because no failure fraction increase due to radiation was observed, we conclude the ten systems have suffered no long term reliability degradation since they were irradiated in 1969. Several considerations must be kept in mind when accepting the statement that the test radiation did not affect the failure fraction. The systems were irradiated with bremsstrahlung (average energy about 4.2 MeV). Testing with a different spectrum, with a neutron source, or with different dose or rate levels might produce different failure records and correlations. To make MTBF estimates, the modules will have to be monitored for several more years to see if enough failures occur.

REFERENCES

1. Klingensmith, R. W., TREE Simulation Facilities (Edition I), DASA-2432, Battelle Memorial Institute, Columbus, OH, September 1970. Cf. p. 3.8-6.

2. Pfeffer, et al., A Portable Calorimetry System for Calibration of Nuclear Weapon Simulator Dosimetry, ECOM-4375, US Army Electronics Command, Fort Monmouth, NJ, December 1975. Cf. p. 77.

APPENDIX A

SUMMARIZED MODULE PRINTOUT DATA

All:

	No primary failure	Primary failure	
Not irradiated	1024	20	1044
Irradiated	637	13	650
	1661	33	1694

Power:

	No primary failure	Primary failure	
Not irradiated	303	9	312
Irradiated	194	7	201
	497	16	513

Logic:

	No primary failure	Primary failure	
Not irradiated	444	7	451
Irradiated	269	3	272
	713	10	723

Analog:

	No primary failure	Primary failure	
Not irradiated	277	4	281
Irradiated	174	3	177
	451	7	458

Table 1. Breakdown of Module Data from Printout.

APPENDIX B

LONG TERM FAILURE FRACTION STATISTICS

All:	Expected / Observed	No primary failure	Primary failure	
Not irradiated		1023.6623 \newline 1024	20.337662 \newline 20	1044
Irradiated		637.33766 \newline 637	12.662337 \newline 13	650
		1661	33	1694

Table 2. Overall Observed and Expected Module Data.

$$\chi^2 = \left(\sum \frac{D^2}{E} \right) - N =$$

$$
\begin{array}{r}
1024.3378 \\
19.667944 \\
636.66251 \\
+ \quad 13.346667 \\
\hline
1694.014921 \\
-1694.000000 \\
\hline
.014921
\end{array}
$$

Comparing with $\chi^2_{\substack{d.f. = 1 \\ \alpha = .05}}$ = 3.84146 shows:

Test is _not_ significant, i.e., data does not provide sufficient reason to reject the hypothesis that failure is independent of whether or not irradiated.

Expected Observed	No primary failure	Primary failure	
Not irradiated	302.269 303	9.7309941 9	312
Irradiated	194.73099 194	6.2690058 7	201
	497	16	513

Power:

Table 3. Power Subset Observed and Expected Module Data.

$$\chi^2 = \left(\sum \frac{D^2}{E} \right) - N = $$

$$
\begin{array}{r}
303.73276 \\
8.3239183 \\
193.27175 \\
+\ \underline{7.8162314} \\
513.1446597 \\
-\underline{513.0000000} \\
.1446597
\end{array}
$$

which is less than 3.84146.

Therefore the data does not provide sufficient reason to reject the hypothesis that failure is independent of whether or not irradiated.

Logic: The expected (under the hypothesis of independence) number of primary failures among the irradiated items is $\frac{272*10}{723} = 3.76$. Since this is less than 5, we do not have enough data to perform a χ^2 test in this set. Therefore we instead perform the following small sample test of independence:

P (3 or fewer irradiated | 10 drawn from 723, of which 272 irradiated and 451 not irradiated) =

$$= \sum_{i=0}^{3} \frac{\binom{272}{i}\binom{451}{10-i}}{\binom{723}{10}} \geq \frac{\binom{272}{3}\binom{451}{7}}{\binom{723}{10}} \doteq .24 > .05 \ .$$

Therefore the data does not provide sufficient reason to reject the hypothesis that failure is independent of whether or not irradiated, at the 5% level of significance for small samples.

Analog: The expected number of failures among the unirradiated is 4.29 and among the irradiated is 2.71. Since both are less than 5, we do not perform a χ^2 test on this set either. The small sample test yields:

P (3 or fewer irradiated | 7 drawn from 458, of which

177 irradiated and 281 not irradiated) $=$

$$= \sum_{i=0}^{3} \frac{\binom{177}{i}\binom{281}{7-i}}{\binom{458}{7}} \geq \frac{\binom{177}{3}\binom{281}{4}}{\binom{458}{7}} \doteq .29 > .05 .$$

Therefore the data again does not provide sufficient reason to reject the hypothesis that failure is independent of whether or not irradiated at the 5% level of significance for small samples.

APPENDIX C
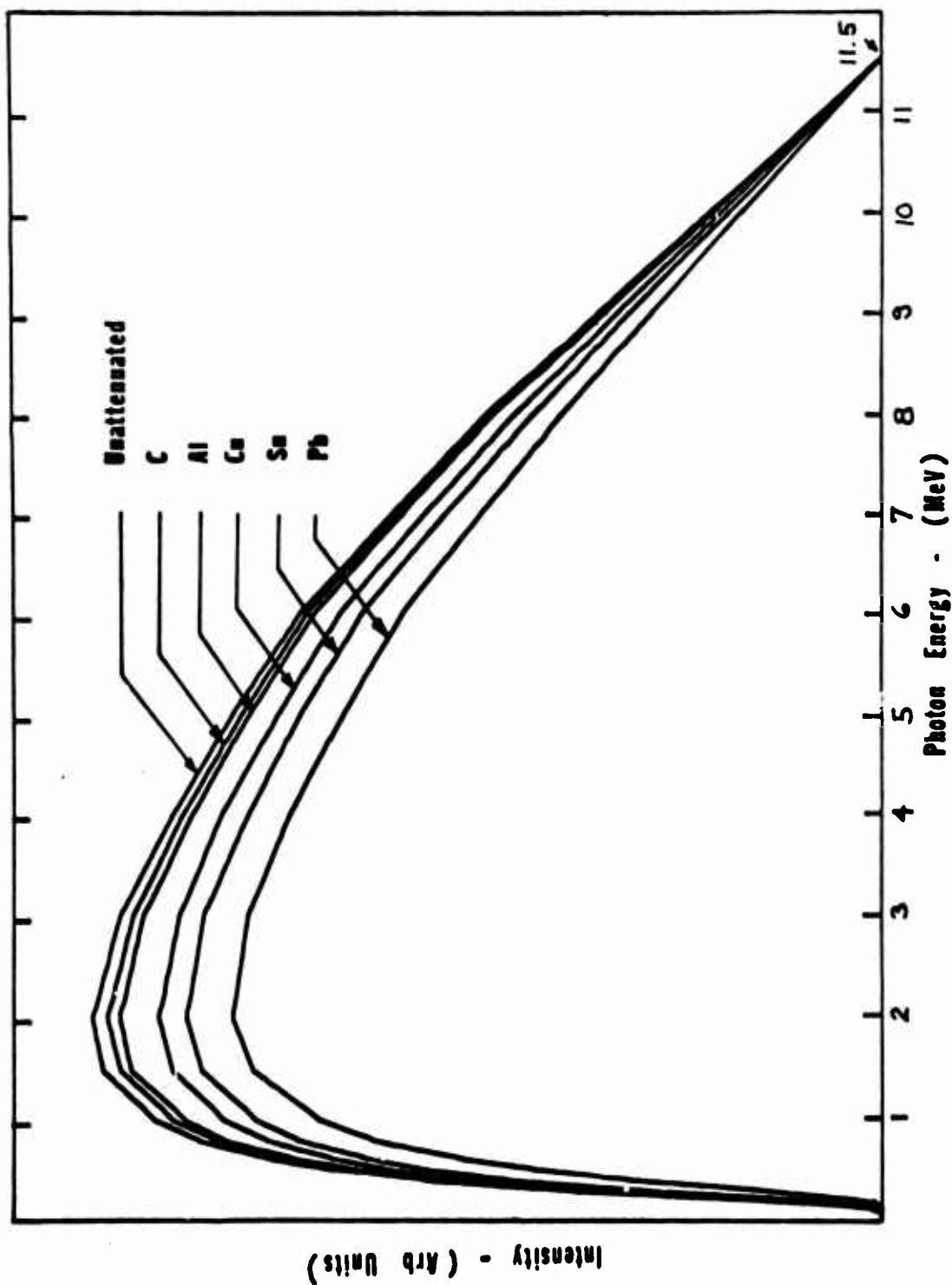
PULSERAD 1590 OUTPUT SPECTRUM

(This is Figure 14a in reference 2.)

Figure 1. Bremsstrahlung Energy Spectra at Element Centers.